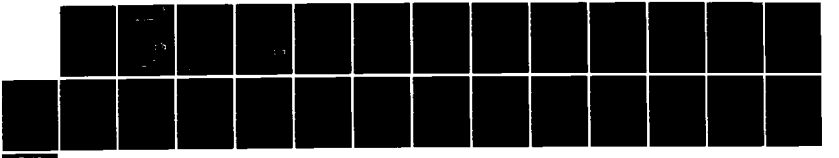
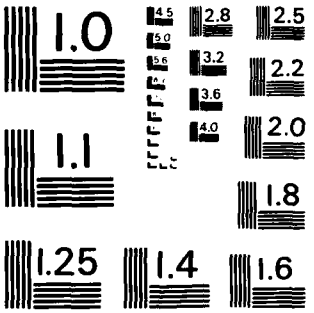
AD-A148 396 SOLITONS AND SEASAT(U) MITRE CORP MCLEAN VA K M CASE 1/1
AUG 84 JSR-84-203D F19628-84-C-0001

UNCLASSIFIED F/G 20/4 NL



END
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Solitons and SEASAT

AD-A148 396

DTIC FILE COPY

DTIC
ELECTE
DEC 10 1984
B

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

MITRE

84 12 10 092

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER JSR-84-203D	2. GOVT ACCESSION NO. A148396	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Solitons and SeaSat		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) K. M. Case		8. CONTRACT OR GRANT NUMBER(s) F19628-84-C-0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS The MITRE Corporation 1820 Dolley Madison Blvd. McLean, VA 22102		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE: August 1984 13. NO. OF PAGES: 18
14. MONITORING AGENCY NAME & ADDRESS (if diff. from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this report)

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

It has been suggested that Soliton formation might be relevant to SeaSat observations. It has also been said that there are no Solitons in more than one space dimension. The second statement is demonstrated to be false. The Kadomtsev-Petviashvile equation relevant to Internal Waves is shown not to have Soliton solutions. This lends support to the view that Solitons and SeaSat have little in common.

DD FORM 1 JAN 73 1473
EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Solitons and SEASAT

K. M. Case

August 1984

JSR-84-203D

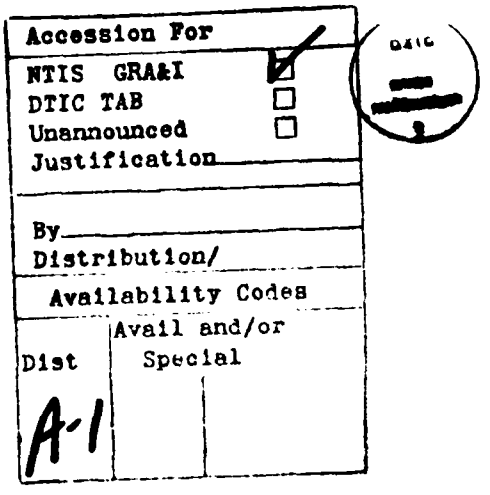
Approved for public release, distribution unlimited

DTIC
ELECTE
DEC 10 1984
S D
B

JASON
The MITRE Corporation
1820 Dolley Madison Boulevard
McLean, Virginia 22102

ABSTRACT

It has been suggested that Soliton formation might be relevant to SeaSat observations. It has also been said that there are no Solitons in more than one space dimension. The second statement is demonstrated to be false. The Kadomtsev-Petviashvile equation relevant to Internal Waves is shown not to have Soliton solutions. This lends support to the view that Solitons and SeaSat have little in common.



1.0 INTRODUCTION

The persistence of long V-shaped wakes observed by SeaSat has led to suggestions that the phenomena may be related to Internal Wave Solitons. Most observations were made under conditions for which one would have little or no reason to expect Solitons to be relevant. However, there is one case (Rev. 407) for which one might think otherwise. This was a big ship in shallow water with a strong thermodine.

A priori there is little likelihood that the equations describing internal waves generated by ships will admit Soliton solutions. (By a Soliton we mean a non-singular disturbance localized in space at any time which retains its integrity on interactions with similar disturbances.) While there are many equations in one space dimension which have Soliton solutions, little is known about spaces of higher dimensions. (Indeed it is sometimes said that there are no true solitons in case the number of space dimensions is greater than one. Below we will see this is not true.)

Since the paradigm of an equation describing Solitons is the Korteineg-deVries (KdV) equation it is natural to take as our starting point an equation closely related to this which does

describe fully three dimensional internal waves. (The class of solutions described is not exactly those we would expect to be ship produced. However, it is hoped that the results obtained will give support to our conviction that Internal Wave Solitons are not relevant for the SeaSat photographs.)

The equation we have in mind is

$$u_t + \partial_x^{-1} u_{yy} + \partial_x (3u^2 + u_{xx}) = 0 \qquad (1)$$

where

$$\partial_x^{-1}\phi = 1/2 \left\{ \int_{-\infty}^{x} - \int_{x}^{\infty} \right\} \phi(x') \, dx'$$

Closely related to Eq. (1) is the equation

$$u_t - \partial_x^{-1} u_{yy} + \partial_x (3u^2 + u_{xx}) = 0 \qquad (2)$$

The Eqs. (1) and (2) are known as the Kadomtsev - Petviashvili (1) equations. A derivation of Eq. (1) in the case of internal waves is given in reference (2). An important point is that for internal waves the sign of the term in Eq. (1) involving u_{yy} is unambiguously required to be plus. (There are physical situations

where Eq. (2) can hold. An example is when capillarity is important.)

Our main result is the following: The extension of the N-Soliton solutions of K-deV to solutions of Eqs. (1) and (2) generally break up asymptotically into K-deV Solitons moving in arbitrary directions in the x-y plane. (These are then plane waves.) They are physically unacceptable as being non-localized. However, for special values of the parameters these solutions are localized in x,y. However, for Eq. (1) these localized solutions are singular. Hence these solutions again are not physical. (This is not so for Eq. (2). True localized, non-singular, non-interacting "lumps" result. We include these primarily to show that multi-dimensional Solitons do indeed exist.)

In Section 2 the formalism used by Zakharov and Shabat (3) to integrate the K-P equations is summarized. The generalization of the N-Soliton KdeV solution is given in Section 3. In Section 4 the "lumps" which result when special relations exist between the N-Soliton parameters is presented.

2.0 FORMALISM

Zakharov and Shabat (3) have introduced a method to integrate Eqs. (1) and (2). We summarize this here.

Let $F(x,z;y,t)$ satisfy the two equations

$$\frac{1}{4}\frac{\partial F}{\partial t} + \frac{\partial^3 F}{\partial x^3} + \frac{\partial^3 F}{\partial z^3} = 0 , \qquad (3)$$

and

$$\frac{1}{\sqrt{3}}\frac{\partial F}{\partial y} + \frac{\partial^2 F}{\partial x^2} - \frac{\partial^2 F}{\partial z^2} = 0 . \qquad (4)$$

Determine $K(x,z;y,t)$ from the Volterra equation

$$F(x,z) + K(x,z) + \int_x^\infty K(x,s)\, F(s,z)\,ds = 0 \qquad (5)$$

(Here we have suppressed the parametric arguments y and t.)

Then they show that

$$u = 2\frac{d}{dx}K(x,x) \tag{6}$$

satisfies Eq. (1).

To find solutions of Eq. (2) we merely note that from any solution of Eq. (1) we can obtain a solution of Eq. (2) by the replacement $y \to iy$.

3.0 GENERALIZATION OF THE N-SOLITON K-deV SOLUTIONS

We follow reference (3).

A. Suppose

$$F = e^{-\kappa x - \eta z} M(t,y) \tag{7}$$

From Eq. (3) we find

$$M = C(y)\, e^{4(\kappa^3 + \eta^3)\, t}\ , \tag{8}$$

Then Eq. (4) gives

$$C = M_o e^{-\sqrt{3}\ (\kappa^2 - \eta^2)\, y}\ , \tag{9}$$

i.e

$$M = M_o e^{\left[\sqrt{3}\ (\eta^2 - \kappa^2)y + 4(\kappa^3 + \eta^3)t\right]} \tag{10}$$

Our Gelfand-Levitan Equation (5) becomes

$$K(x,z) + Me^{-\kappa x - \eta z} + \int_x^\infty K(x,s)\, Me^{-\kappa s} e^{-\eta z} - 0\ , \tag{11}$$

Clearly $K(x,z) = K(x)\, e^{-\eta z}$. Inserting in Eq. (11) yields

$$K(x) + Me^{-\kappa x} + \frac{M\, e^{-(\kappa + \eta)x}}{\kappa + \eta} \quad K = 0 \tag{12}$$

Solving gives

$$K(x,z) = \frac{-M\, e^{-(\kappa x + \eta z)}}{1 + \frac{M}{\kappa + \eta} e^{-(\kappa + \eta)x}} \tag{13}$$

Then

$$K(x,x) = \frac{-M\, e^{-(\kappa + \eta)x}}{1 + \frac{M}{\kappa + \eta} e^{-(\kappa + \eta)x}}$$

$$\equiv \frac{\partial}{\partial x} \ln \left[1 + \frac{M}{\kappa + \eta} e^{-(\kappa + \eta)x}\right]$$

and so

$$u = 2 \frac{\partial^2}{\partial x^2} \ln \left[1 + \frac{M}{\kappa + \eta} e^{-(\kappa + \eta)x}\right] \tag{14}$$

Defining x_o by

$$(\kappa + \eta)\, x_o = \ln \frac{M}{\kappa + \eta}$$

gives

$$x_o = \frac{1}{\kappa + n} \ln \frac{M_o}{\kappa + n} + \sqrt{3}\,(\eta - \kappa)y + 4(\kappa^2 - \kappa\eta + \eta^2)t \quad (15)$$

Then Eq. (14) becomes

$$u = \frac{\frac{1}{2}(\kappa + \eta)^2}{\cosh^2 \frac{(\kappa + \eta)}{2}(x - x_o)} \quad (16)$$

To interprete this consider $\kappa = \eta$ then

$$U = \frac{2\kappa^2}{\cosh^2 \kappa(x - x_o)} \quad (17)$$

with

$$x_o = \text{constant} + 4\kappa^2 t$$

This is just a K-deV Soliton. For $\kappa \neq \eta$ the solution (16) is then a K-deV type soliton propagating at an arbitrary angle with respect to the x-axis. This is a plane wave - it is constant on the line

$$x - \sqrt{3}\,(\eta^2 - \kappa^2)y = \text{constant} ,$$

and hence physically really not acceptable.

B) The above is readily extended to get the 2-dimensional extension of the N-Soliton K-deV solution. Thus we generalize Eq. (10) by choosing

$$F = \sum_n M_n (t,y) e^{-\kappa_n x - \eta_n z} \tag{18}$$

Since Eq. (3) and (4) are linear we have in analogy to Eq. (10)

$$M_n = M_n(o)\, e^{\left[\sqrt{3}\,(\eta_n^2 - \kappa_n^2)y + 4(\kappa_n^3 + \eta_n^3)t\right]} \tag{19}$$

The degenerate integral equation for $K(x,z)$ is then satisfied by

$$K(x,z) = \sum_n K_n(x)\, e^{-\eta_n z} \tag{20}$$

where

$$K_n(x) + M_n\, e^{-\kappa_n x} + M_n \sum_m \frac{e^{-(\kappa_n + \eta_n)x}}{\kappa_n + \eta_m} K_m(x) = 0 \tag{21}$$

This is readily solved using Cramer's rule. Thus

$$K_n(x) = \frac{A_n(x)}{\Delta(x)} \tag{22}$$

where

$$\Delta = \det \left\{ \delta_{nm} + \frac{M_n\, e^{-(\kappa_n + \eta_m)x}}{\kappa_n + \eta_m} \right\} \tag{23}$$

and A_n is obtained from Δ by replacing the n'th column of the matrix by the vector

$$(-M_1 e^{-\kappa_1 x}\ ,\ -M_2 e^{-\kappa_2 x}\ ,\ \ldots)\ .$$

Suggested by the form of Eq. (14) we look at $\sum_n A_n(x)\, e^{-\eta x}$ and verify that

$$\sum_n A_n(x)\, e^{-\eta x} = \frac{\partial}{\partial x}\, \Delta(x)$$

therefore $K(x,x) = \frac{\partial}{\partial x} \ln \Delta$ and so

$$u(x) = 2\, \frac{\partial^2}{\partial x^2} \ln \Delta \tag{24}$$

To interpret this result we consider the limit as y, t go to infinity. Assuming no special relations between the

various pairs (κ_n, η_n) . Then we note that for large $|y|$, $|t|$ there will be regions where one of the M_n (say M_j) is much larger than all others. Hence then

$$\Delta \approx 1 + \frac{M_j \, e^{-(\kappa_j + \eta_j)x}}{\kappa_j + \eta_j} , \tag{25}$$

which is just the single soliton result of Eq. (14). Thus asymptotically the solution breaks up into a sum of the simple "plane soliton" solutions.

4.0 DEGENERATE CASES

It is well known that the K-deV equation has in addition to solutions like those of Eq. (24) solutions which are rational functions of the coordinates. These can be obtained by making a suitable ansatz for the form of solution. This is

$$U = \sum_n \frac{c_n}{[x - a_n(t)]^\alpha} \tag{26}$$

Inserting in the K-deV shows that this will be a solution if $\alpha = 2$, the c_n are constants and the a_n satisfy simple coupled ordinary differential equations. An alternative approach is to take the general solution of Eq. (24), specify relations between the parameters, κ_n, η_n, and pass to limits. This is the procedure given in reference (4) - and the one we will follow.

We have seen that a solution is obtained from Eq. (24) with Δ given by Eq. (23). Introduce λ_n, γ_n by

$$\kappa_n = \frac{\lambda_n + \gamma_n}{2} \quad , \quad \eta_n = \frac{\lambda_n - \gamma_n}{2} \tag{27}$$

then choosing $M_n(0) = -a_n \lambda_n$ we have $\Delta = \det \Gamma$ where

$$\Gamma_{nn} = \delta_{nn} + \frac{2\,M_n}{\gamma_n - \gamma_m + \lambda_n + \lambda_m}\, e^{\frac{-[\lambda_n + \gamma_n + \lambda_m - \gamma_m]x}{2}} \tag{28}$$

$$M_n = -\,a_n \lambda_n\, e^{\lambda_n [\ ]_n}\,, \tag{29}$$

$$[\ ]_n = \left[-\sqrt{3}\ \ \gamma_n y + (\lambda_n^2 + 3\gamma_n^2)t\right] \tag{30}$$

Now look at the limit as all $\lambda_n \to 0$.

Assuming $a_n \sim 1 + \zeta_n\, \lambda_n$ we have on expanding in λ_n and keeping only matrix elements of first order in the λ_n

$$\Gamma_{nn} = \lambda_n d_n$$

$$n \neq m \qquad \Gamma_{nm} = \frac{-2\lambda_n}{\gamma_n - \gamma_m} \tag{31}$$

where

$$d_n = x - \zeta_n + \sqrt{3}\ \gamma_n y - 3\gamma_n^2\ t \tag{32}$$

Then

$$\det \Gamma = (\Pi \lambda_n) \det \Gamma' \tag{33}$$

with $\Gamma'_{nn} = d_n$

$$n \neq m \quad \Gamma'_{nm} = \frac{-2}{\gamma_n - \gamma_m} . \tag{34}$$

We can then write

$$u = 2 \frac{\partial^2}{\partial x^2} \ell n \det \Gamma' \tag{35}$$

The essential points are seen by considering the case of N = 2. Then

$$\Delta' = \det \Gamma' = d_1 d_2 + \frac{4}{(\gamma_1 - \gamma_2)^2} \tag{36}$$

$$= [x - \zeta_1 + \sqrt{3}\gamma_1 y - 3\gamma_1^2 t][x - \zeta_2 + \sqrt{3}\gamma_2 y - 3\gamma_2^2 t]$$

$$+ \frac{4}{(\gamma_1 - \gamma_2)^2} \tag{37}$$

Clearly u is then a rational function of x, y, t. Consider various possibilities for ζ_n , γ_n .

(i) ζ_n , γ_n real. The solution is clearly singular.

(There are points where $\Delta' = 0$.)

(ii) ζ_n , γ_n complex. For the solution to be real we must have

$$\zeta_1 = \zeta \ , \quad \zeta_2 = \zeta^* \qquad \gamma_1 = \gamma \ , \quad \gamma_2 = \gamma^*$$

Then

$$\Delta' = -\frac{1}{\gamma_1^2} + |x - \zeta + \sqrt{3}\,\gamma y - 3\gamma^2 t|^2 \tag{38}$$

The second term can vary from 0 to ∞ and therefore Δ' vanishes at least once.

These rational solutions of Eq. (1) are physically unacceptable.

On the other hand we noted that a solution of Eq. (2) is obtained from one of Eq. (1) by the replacement $y \to iy$. In such a case

$$\Delta' \to [x - \zeta_1 + i\sqrt{3}\gamma_1 y - 3\gamma_1^2 t][x - \zeta_2 + i\sqrt{3}\gamma_2 y - 3\gamma_2^2 t]$$

$$+ \frac{4}{(\gamma_1 - \gamma_2)^2} \tag{39}$$

Again if the γ_r , γ_r are real the solution is singular. If these are complex we must require in order that the solution be real that $\gamma_1 \equiv \gamma$, $\gamma_2 = -\gamma^*$. In this case

$$\Delta' = \frac{1}{\gamma_r^2} + |x - \zeta + r\sqrt{3}\ \gamma y - 3\gamma^2 t|^2 \ . \tag{40}$$

If γ_r (real part of γ) is non-zero this obviously gives a non-singular solution. It is also well-behaved at infinity. As $|x|$ ($|y|$) go infinity $U \sim \frac{1}{x^2}\left(\frac{1}{y^2}\right)$. .

5.0 CONCLUSIONS

Two dimensional Solitons exist. However, some equations describing internal waves which might be strongly suspected of having Soliton solutions do not.

While not definitive this lends significant support to the view that Solitons have no connection with the phenomena observed by SeaSat.

REFERENCES

(1) B. Kadomtsev and V. Petviashvili, Sov. Phys. Dokl. 15 (1970), 539.

(2) Case, K. N. and Rosenbluth, M. N., JSR-76-29 (June 1977).

(3) Zakharov, V. E. and Shabat, A. B., Funct. Anal. Appl. 8 (1974) 279.

(4) Manakov, S. V., Zakharov, V. E., Bordag, L. A. Its, A. R., and Matreev, V. B., Physics Letters, 63A, (1977), 205.

DISTRIBUTION LIST

Dr. Marv Atkins
Deputy Director, Science & Tech.
Defense Nuclear Agency
Washington, D.C. 20305

National Security Agency
Attn RS: Dr. N. Addison Ball
Ft. George G. Meade, MD 20755

Mr. Anthony Battista [3]
House Armed Services Committee
2120 Rayburn Building
Washington, D.C. 20515

Mr. Steve Borchardt
Dynamics Technology
Suite 200
22939 Hawthorne Boulevard
Torrance, CA 90505

Mr. Rod Buntzen
NOSC
Code 1603B
San Diego, CA 92152

Dr. Curtis G. Callan, Jr.
Department of Physics
Princeton University
Princeton, NJ 08540

Mr. Gerald Cann
Principal Assistant Secretary
of the Navy (RES&S)
The Pentagon, Room 4E736
Washington, D.C. 20350

Dr. Kenneth M. Case
The Rockefeller University
New York, New York 10021

Dr. Robert Cooper [2]
Director, DARPA
1400 Wilson Boulevard
Arlington, VA 22209

Dr. Roger F. Dashen
Institute for
Advanced Study
Princeton, NJ 08540

Dr. Russ E. Davis
Scripps Institution
of Oceanography
(A-030), 301 NORPAX, UCSD
La Jolla, CA 92093

Defense Technical Information [2]
Center
Cameron Station
Alexandria, VA 22314

The Honorable Richard DeLauer
Under Secretary of Defense (R&E)
Office of the Secretary of
Defense
The Pentagon, Room 3E1006
Washington, D.C. 20301

Director [4]
National Security Agency
Fort Meade, MD 20755
ATTN: Mr. Richard Foss, A05

CAPT Craig E. Dorman
Department of the Navy, OP-095T
The Pentagon, Room 5D576
Washington, D.C. 20350

CDR Timothy Dugan
NFOIO Detachment, Suitland
4301 Suitland Road
Washington, D.C. 20390

Dr. Frank Fernandez
ARETE Assoc.
P.O. Box 350
Encino, CA 91316

DISTRIBUTION LIST

(Continued)

Mr. Richard Gasparovic
APL
Johns Hopkins University
Laurel, MD 20707

Dr. Larry Gershwin
NIO for Strategic Programs
P.O. Box 1925
Washington, D.C. 20505

Dr. S. William Gouse, W300
Vice President and General
Manager
The MITRE Corporation
1820 Dolley Madison Blvd.
McLean, VA 22102

Dr. Edward Harper [10]
SSBN, Security Director
OP-021T
The Pentagon, Room 4D534
Washington, D.C. 20350

Mr. R. Evan Hineman
Deputy Director for Science
& Technology
P.O. Box 1925
Washington, D.C 20505

Dr. Richard Hoglund
Operations Research Inc.
Room 428
1400 Spring Street
Silver Spring, MD 20910

Mr. Ben Hunter [2]
CIA/DDS&T
P.O. Box 1925
Washington, D.C. 20505

The MITRE Corporation [25]
1820 Dolley Madison Blvd.
McLean, VA 22102
ATTN: JASON Library, W002

Mr. Jack Kalish
Deputy Program Manager
The Pentagon
Washington, D.C. 20301

Mr. John F. Kaufmann
Dep. Dir. for Program Analysis
Office of Energy Research, ER-31
Room F326
U.S. Department of Energy
Washington, D.C. 20545

Dr. George A. Keyworth
Director
Office of Science & Tech. Policy
Old Executive Office Building
17th & Pennsylvania, N.W.
Washington, D.C. 20500

Mr. Jerry King [3]
RDA
P.O. Box 9695
Marina del Rey, CA 90291

MAJ GEN Donald L. Lamberson
Assistant Deputy Chief of Staff
(RD&A) HQ USAF/RD
Washington, D.C. 20330

Dr. Donald M. LeVine, W385 [3]
The MITRE Corporation
1820 Dolley Madison Blvd.
McLean, VA 22102

Mr. V. Larry Lynn
Deputy Director, DARPA
1400 Wilson Boulevard
Arlington, VA 22209

DISTRIBUTION LIST

(Continued)

Dr. Joseph Mangano [2]
DARPA/DEO
9th floor, Directed Energy Office
1400 Wilson Boulevard
Arlington, VA 22209

Mr. Walt McCandless
4608 Willet Drive
Annandale, VA 22003

Mr. John McMahon
Dep. Dir. Cen. Intelligence
P.O. Box 1925
Washington, D.C. 20505

Director
National Security Agency
Fort Meade, MD 20755
ATTN: William Mehuron, DDR

Dr. Marvin Moss
Technical Director
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

Dr. Walter H. Munk
9530 La Jolla Shores Drive
La Jolla, CA 92037

Dr. Julian Nall [2]
P.O. Box 1925
Washington, D.C. 20505

Director
National Security Agency
Fort Meade, MD 20755
ATTN: Mr. Edward P. Neuburg
DDR-FANX 3

Prof. William A. Nierenberg
Scripps Institution of
Oceanography
University of California, S.D.
La Jolla, CA 92093

Dr. John Penhune
Science Applications, Inc.
MS 8
1200 Prospect Street
La Jolla, CA 92038

The MITRE Corporation
Attn: Records Resources
1820 Dolley Madison Boulevard
McLean, VA 22102

Mr. Alan J. Roberts
Vice President & General Manager
Washington C^3 Operations
The MITRE Corporation
1820 Dolley Madison Boulevard
Box 208
McLean, VA 22102

Los Alamos Scientific Laboratory
ATTN: C. Paul Robinson
P.O. Box 1000
Los Alamos, NM 87545

Mr. Richard Ross [2]
P.O. Box 1925
Washington, D.C. 20505

Mr. Richard Ruffine
OUSDRE
Offensive & Space Systems
The Pentagon, Room 3E129
Washington, D.C. 20301

Dr. Phil Selwyn
Technical Director
Office of Naval Technology
800 N. Quincy Street
Arlington, VA 22217

Dr. Eugene Sevin [2]
Defense Nuclear Agency
Washington, D.C. 20305

DISTRIBUTION LIST

(Concluded)

Mr. Robert Shaffer
House Arms Services
Room 2343
Rayburn Office Building
Washington, D.C. 20515

Mr. Omar Shemdin
JPL
Mail Stop 183501
4800 Oak Grove Drive
Pasadena, CA 91109

Mr. Robert Shuckman
P.O. Box 8618
Ann Arbor, MI 48107

Dr. Joel A. Snow (2)
Senior Technical Advisor
Office of Energy Research
U.S. DOE, M.S. E084
Washington, D.C. 20585

Mr. Alexander J. Tachmindji
Senior Vice President & General
Manager
The MITRE Corporation
P.O. Box 208
Bedford, MA 01730

Dr. Vigdor Teplitz
ACDA
320 21st Street, N.W.
Room 4484
Washington, D.C. 20451

Mr. Anthony J. Tether
DARPA/STO
1400 Wilson Boulevard
Arlington, VA 22209

Dr. Al Trivelpiece
Director, Office of Energy
Research, U.S. DOE
M.S. 6E084
Washington, D.C. 20585

Mr. Marshal Tulin
Dept. of Mechanical Eng.
University of California
Santa Barbara, CA 93106

Dr. John F. Vesecky
Center for Radar Astronomy
233 Durand Building
Stanford University
Stanford, CA 94305

Mr. James P. Wade, Jr.
Prin. Dep. Under Secretary of
Defense for R&E
The Pentagon, Room 3E1014
Washington, D.C. 20301

Dr. Kenneth M. Watson
2191 Caminito Circulo Norte
La Jolla, CA 92037

Mr. Robert Winokur
Director, Planning & Assess.
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

Mr. Leo Young
OUSDRE (R&AT)
The Pentagon, Room 3D1067
Washington, D.C. 20301

Dr. Fredrik Zachariasen (452-48)
California Institute
of Technology
1201 East California Street
Pasadena, CA 91125

END

FILMED

1-85

DTIC